Monochromator Vibration: Two case studies

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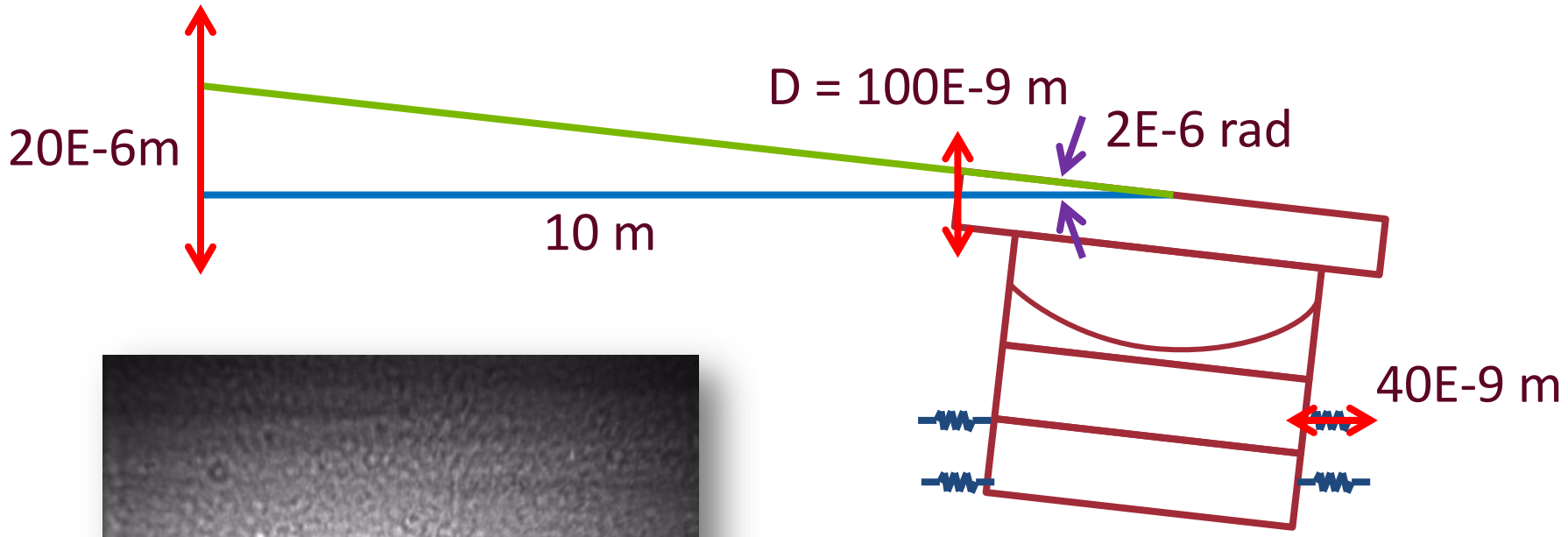
Outline

- Background: what, why, and how
- Case study 1: S07 BM Double Multilayer Monochromator (DMM)
- Case study 2: S02 ID DMM
- Summary of our method
- Conclusions

Vibration diagnosis can be a bit like wandering the Australian outback…

Background: A little (motion) goes a long way



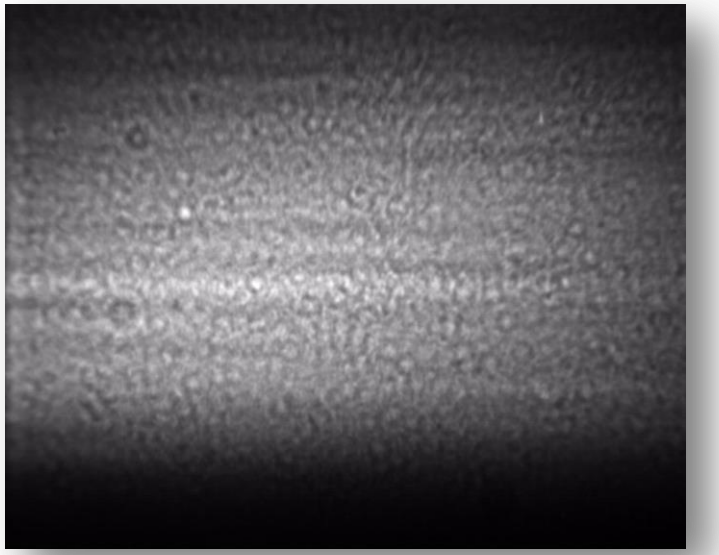
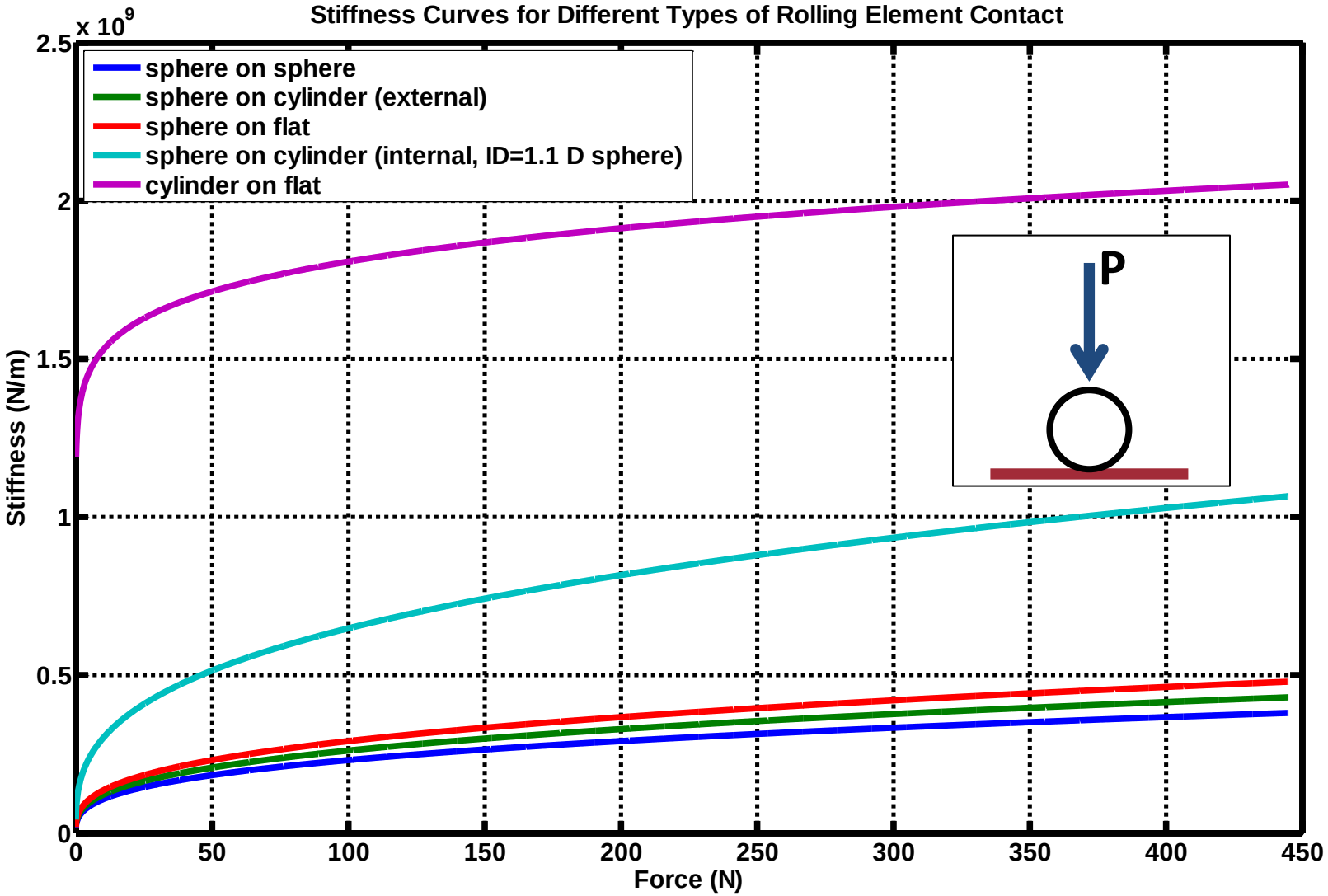


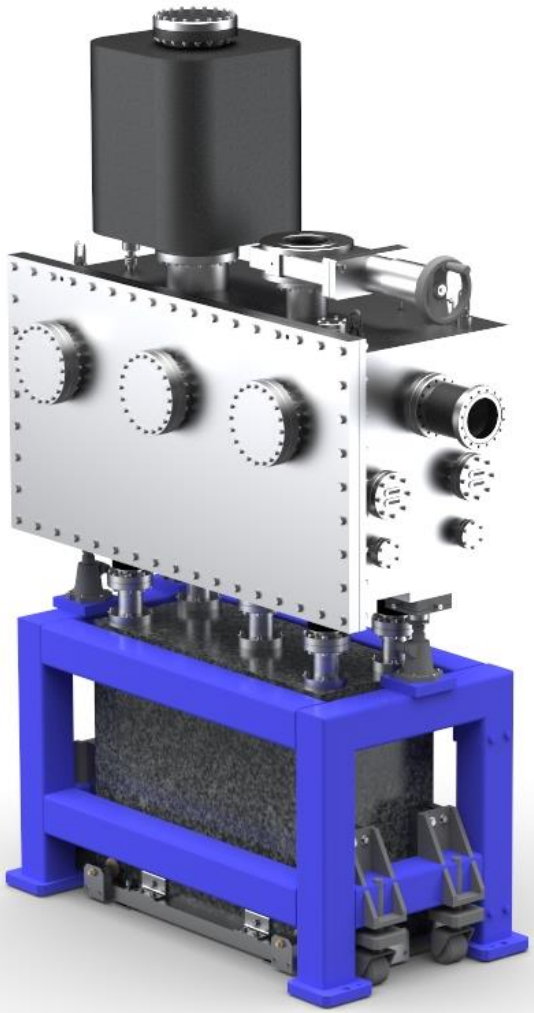
Image of beam from S02 ID Double Multilayer Monochromator

Background: Bearings are most compliant part



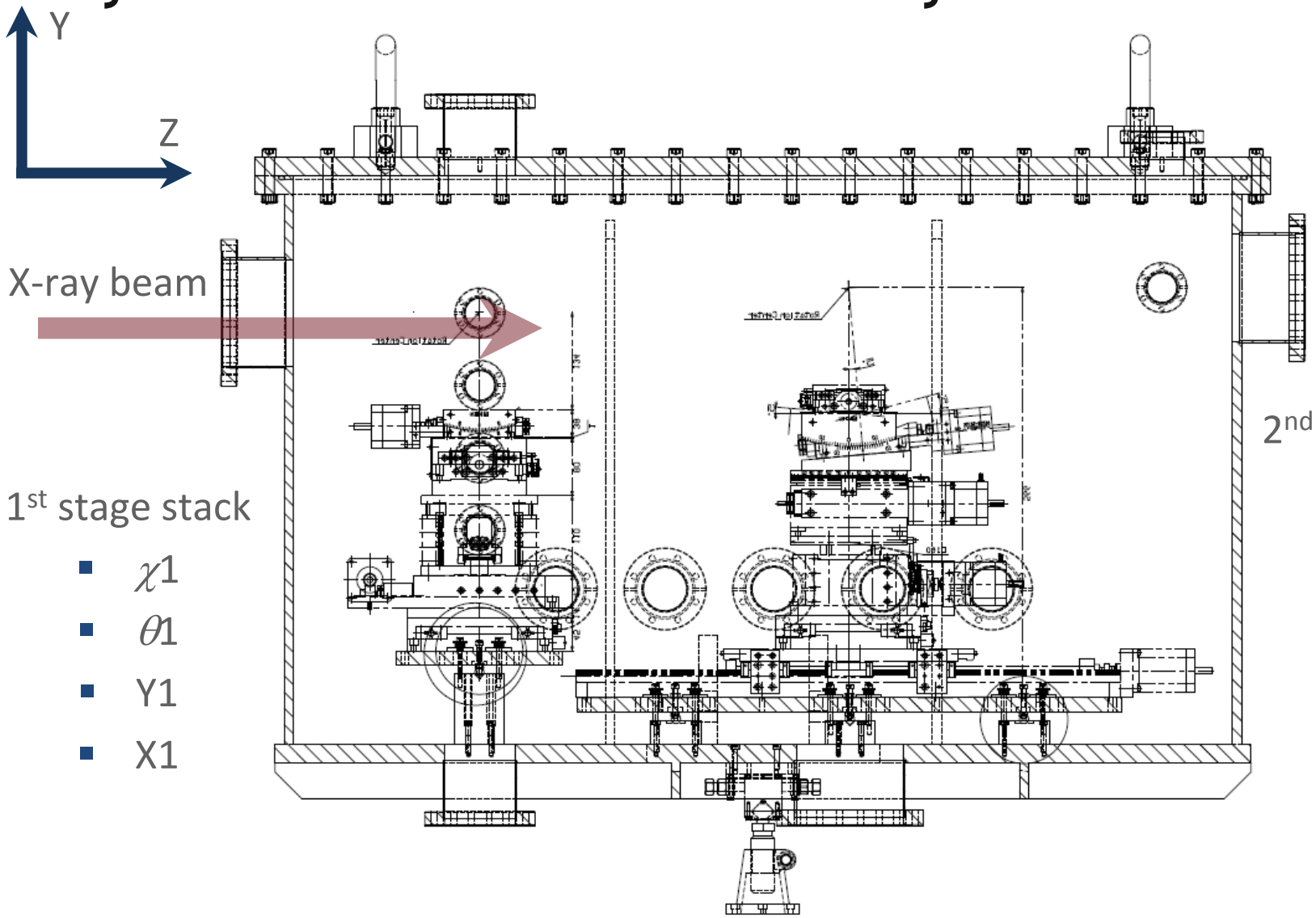
Background: Tell me what's wrong but don't open it up

- 1st check ambient levels
- Measure supports/outside tank
- Characterize beam motion
- Subsequently open instrument to make measurements



S02 DMM

Case Study 1: Sector 7 BM Double Multilayer Mono



1st stage stack

- $\chi 1$
- $\theta 1$
- Y1
- X1

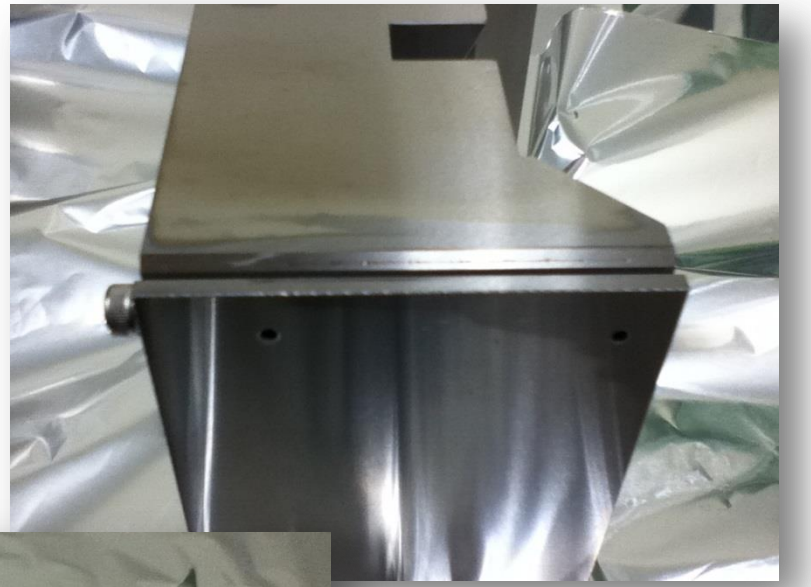
2nd stage stack

- $\chi 2$
- $\theta 2$
- Y2
- X2
- Z2

Case Study 1: Wandering in the outback

- Initial beam characterization was misleading
  - Camera frame rate was insufficient
  - Operational conditions were be different than conditions when imaging beam vibration were different than when measuring vibration
  - A roughing pump was connected to an evacuated flight path in the next hutch
- A number of “mirages”
  - Missing fasteners
  - Broken/incorrect baseplate mounting
  - Damaged vertical stage, fretting
- Cycle times between measurements were long
- Access to internals was limited

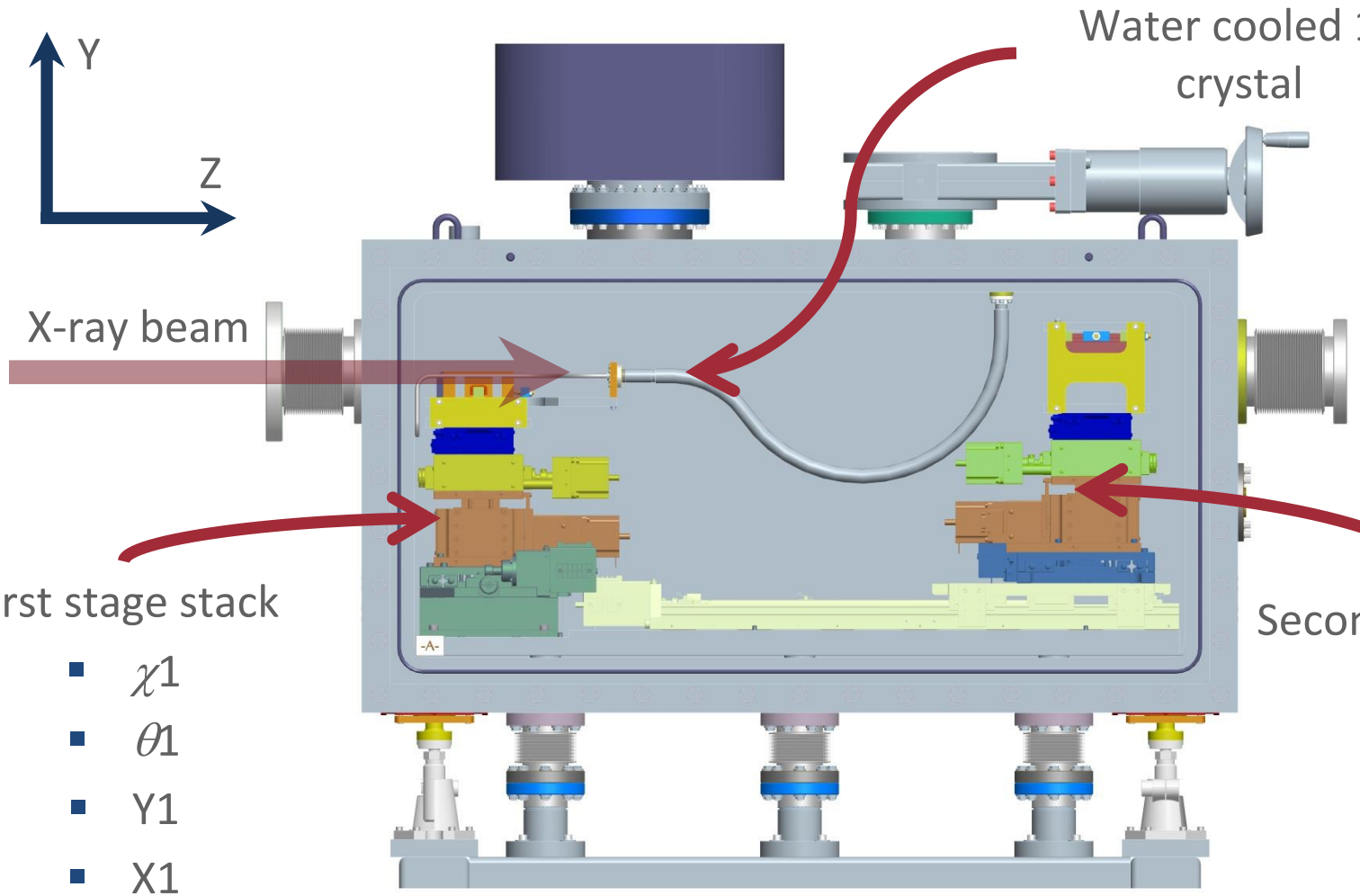
Case Study 1: Mirages



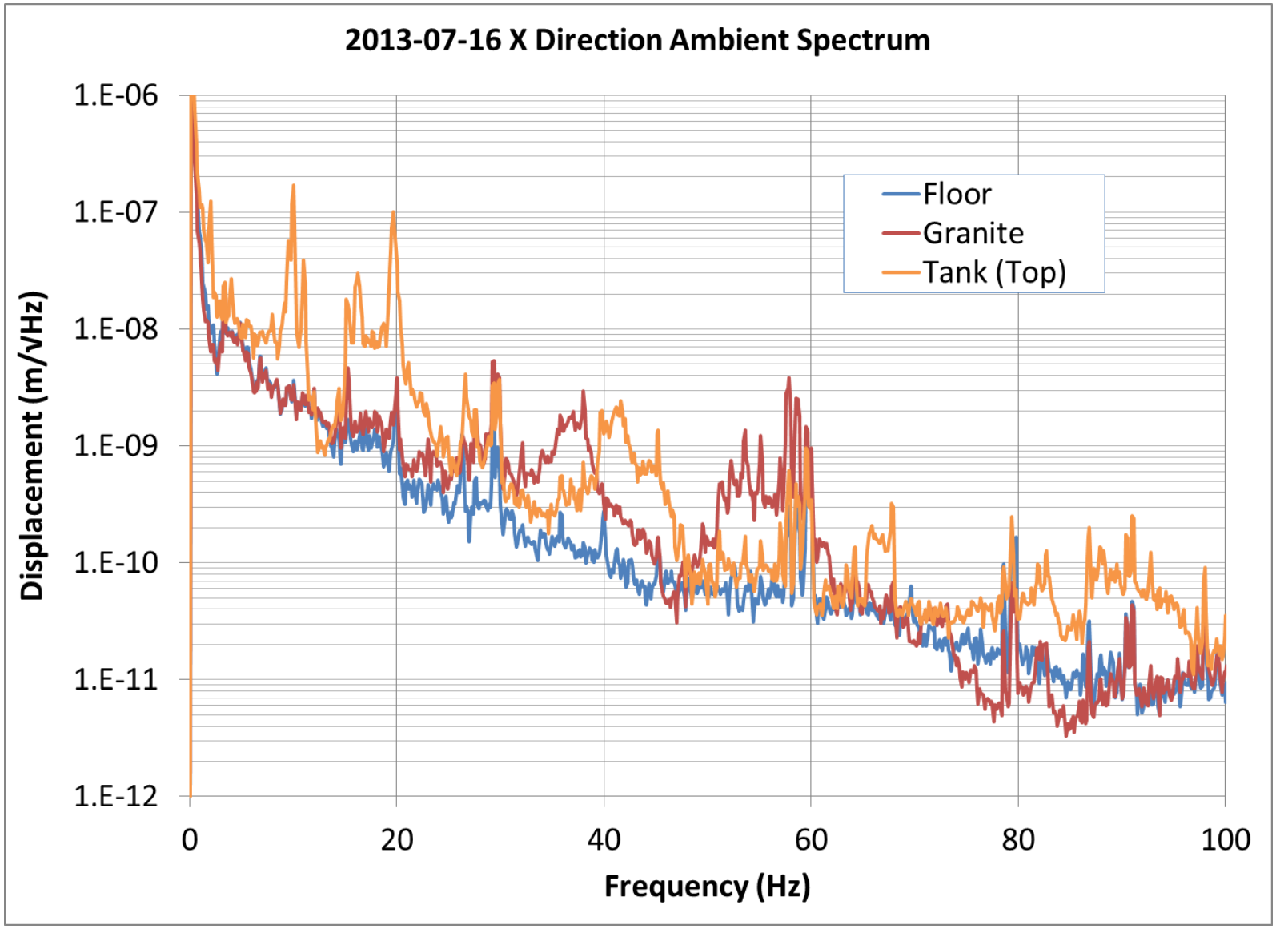
Case Study 1: Oasis on the horizon?

- Lack of good beam=>mechanics correlation caused lots of time to be spent
- Real problems were identified
- However, they were not problems that contributed greatly to beam motion
- Subsequent beam measurements, vibration measurements, and modal analysis located problems
  - 20 Hz peak associated with tank support (also close to 1st crystal stack resonance dominated by Y stage)
  - 37 Hz peak associated with 2nd crystal stack Y stage
- Fix: Eventually replace 2nd crystal Y stage (only enough money for one)

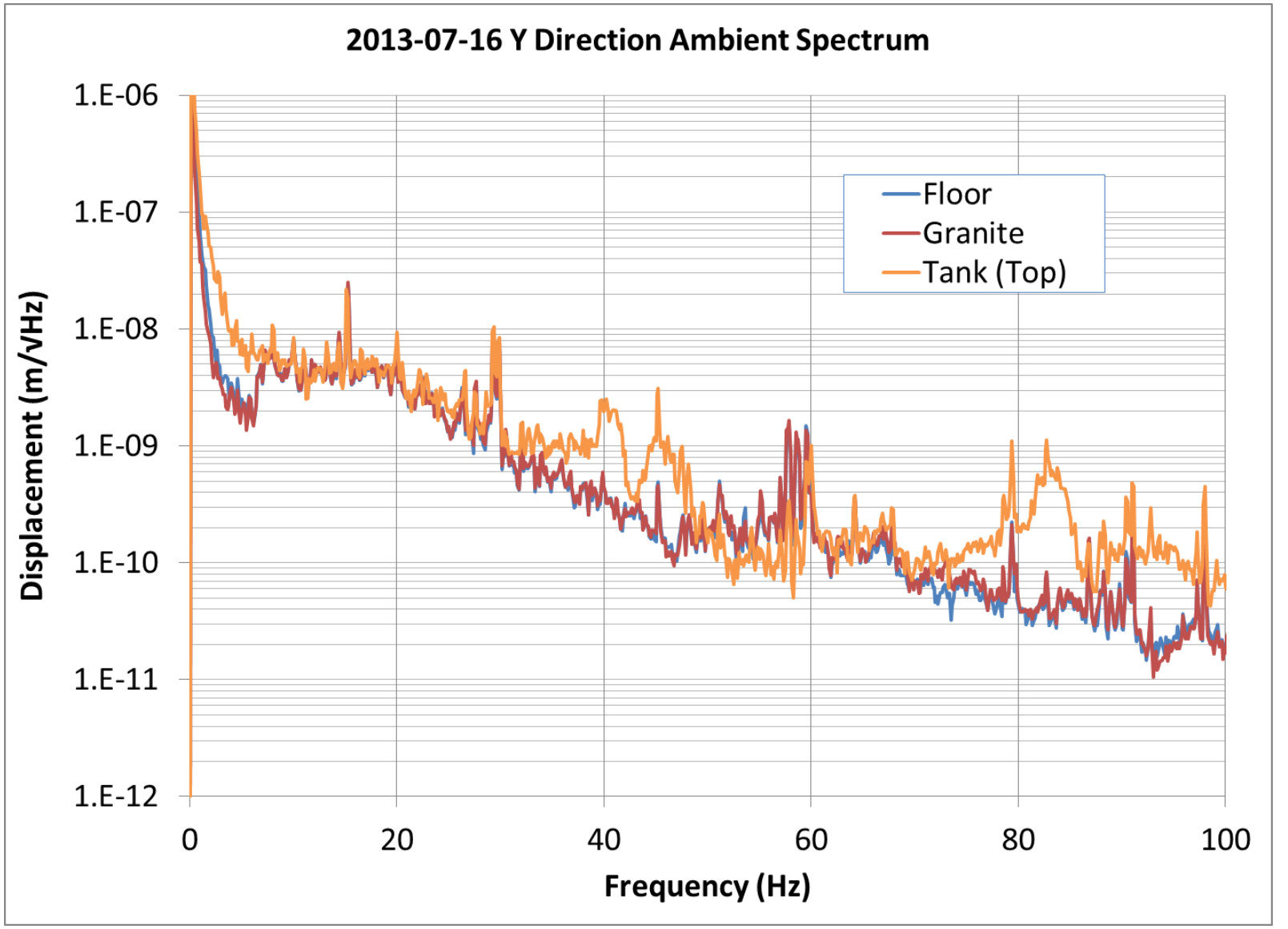
Case Study 2: Sector 2 ID Double Multilayer Mono



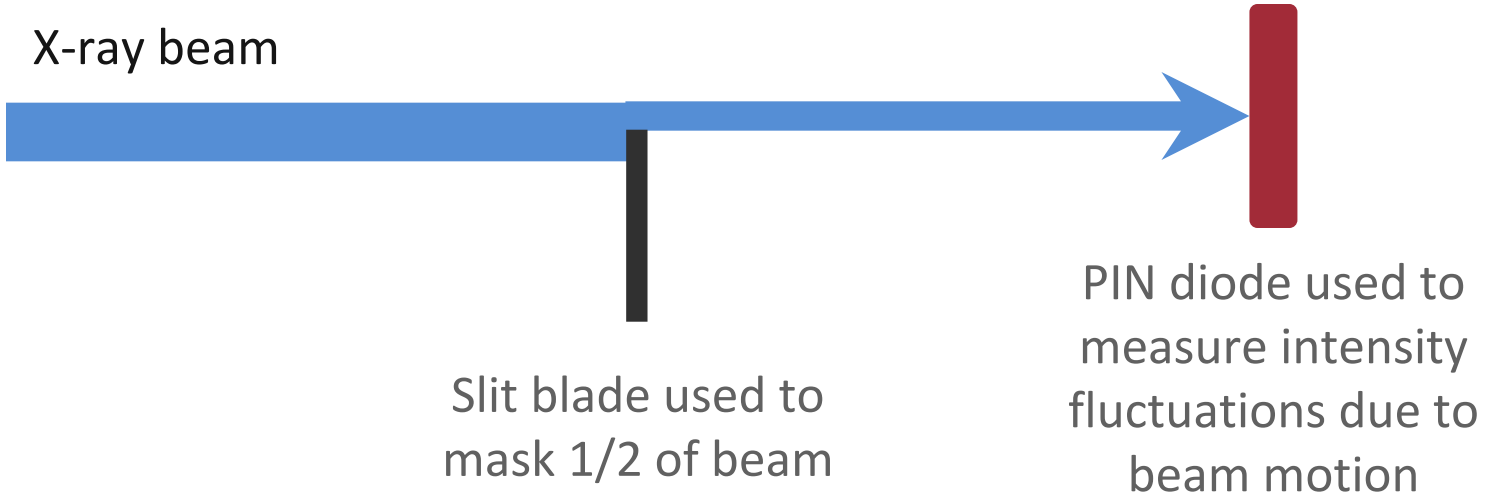
Case Study 2: Transverse direction ambient vibration



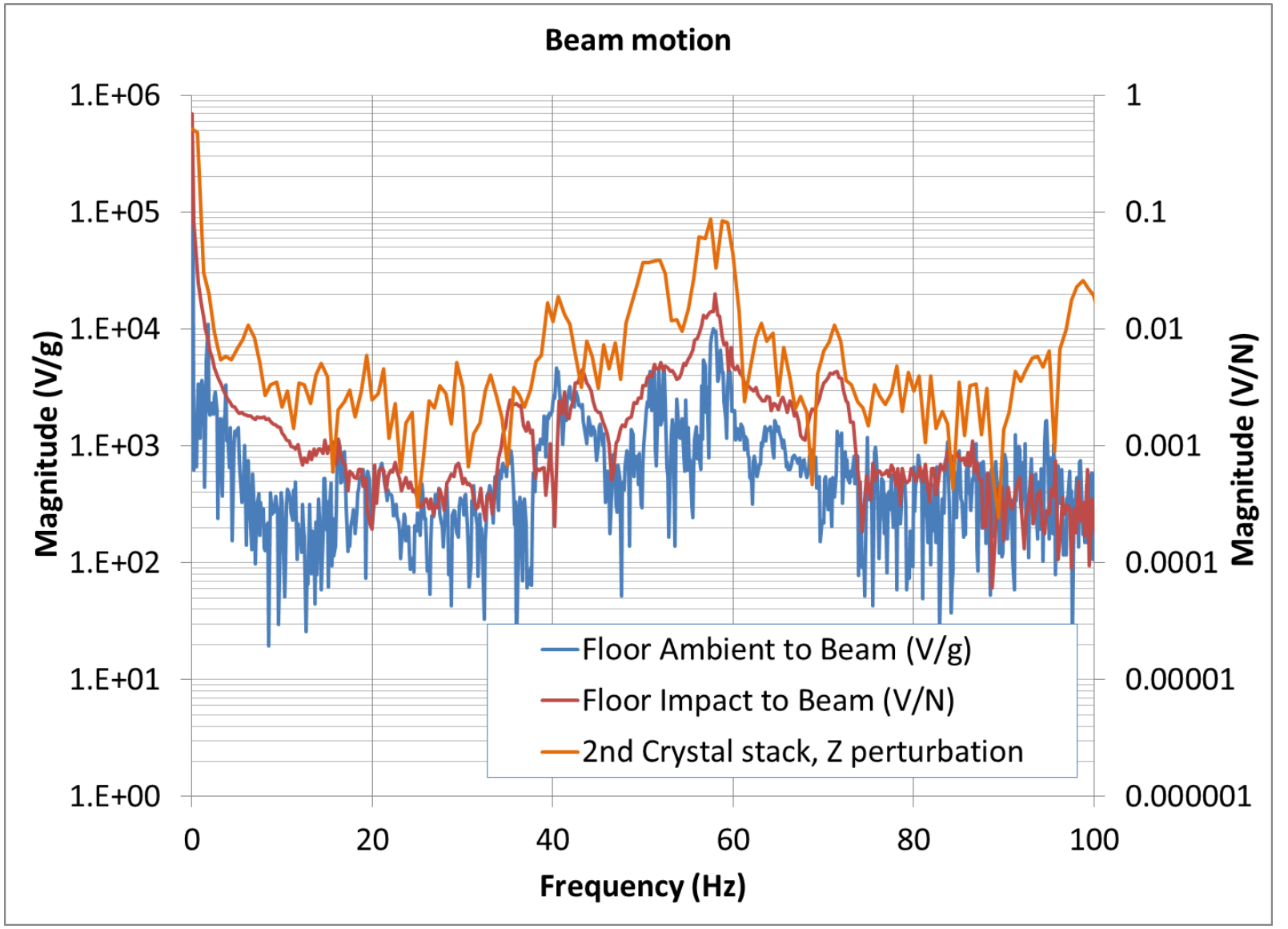
Case Study 2: Vertical direction ambient vibration



Case Study 2: Beam motion measurements

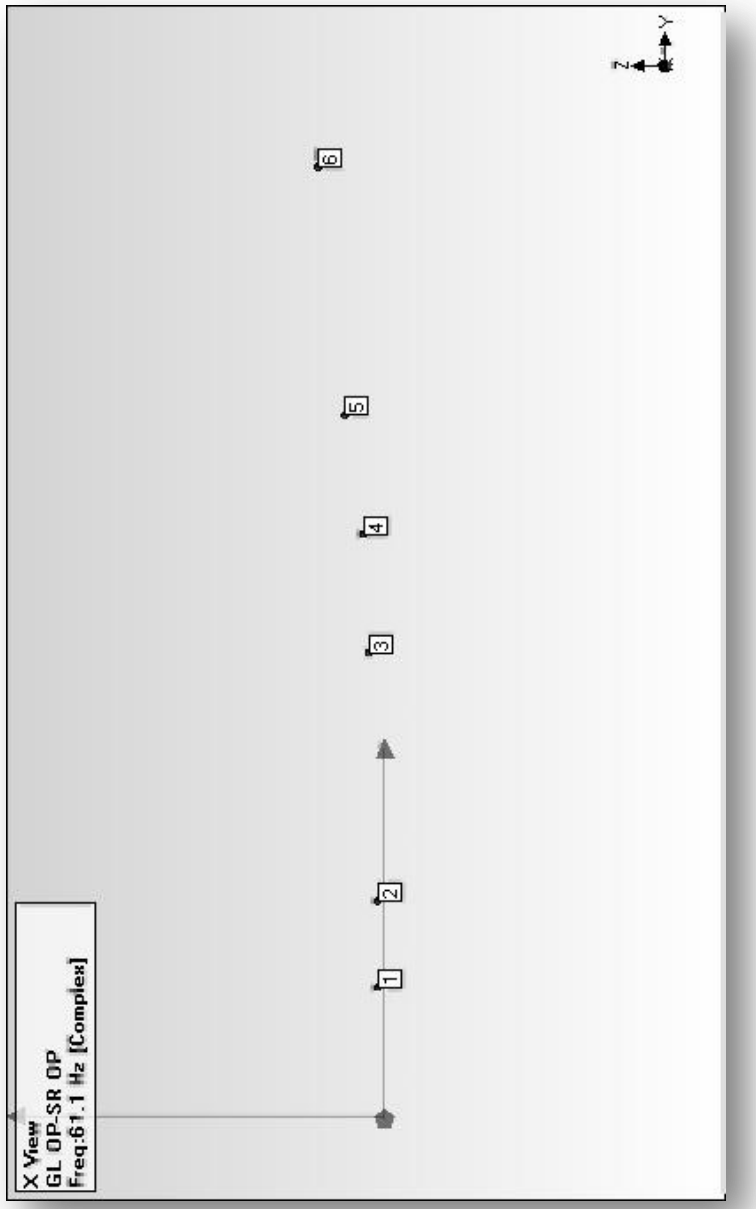


Case Study 2: Beam motion measurements

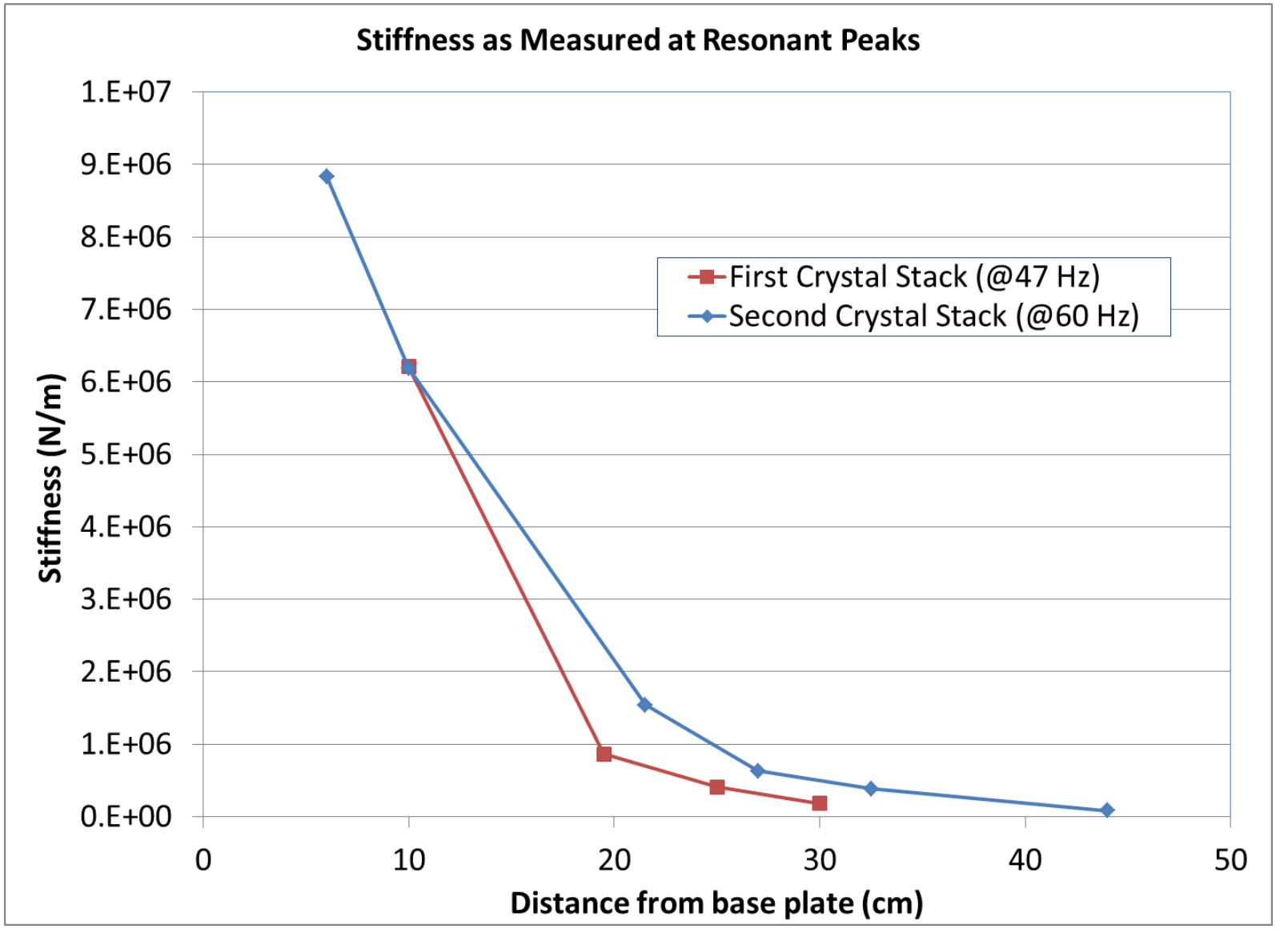


Case Study 2: Modal analysis

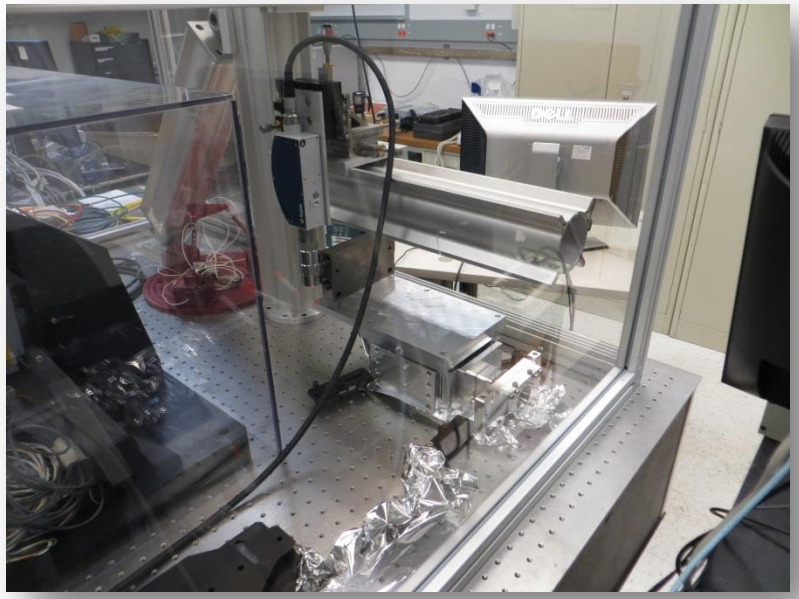
- Impact frequency response functions (FRFs) at each component of each stage stack provide:
  - Direct estimation of stiffness
  - Information to identify mode shapes and natural frequencies
- Each stack has a mode shape that is primarily in the Z direction (rotation about X), which is the worst for beam motion.
- 60 Hz mode for the second crystal stack is shown to the right
- Points 3-6 are moving portion of Y stage and above
- Y stage is “weak link”



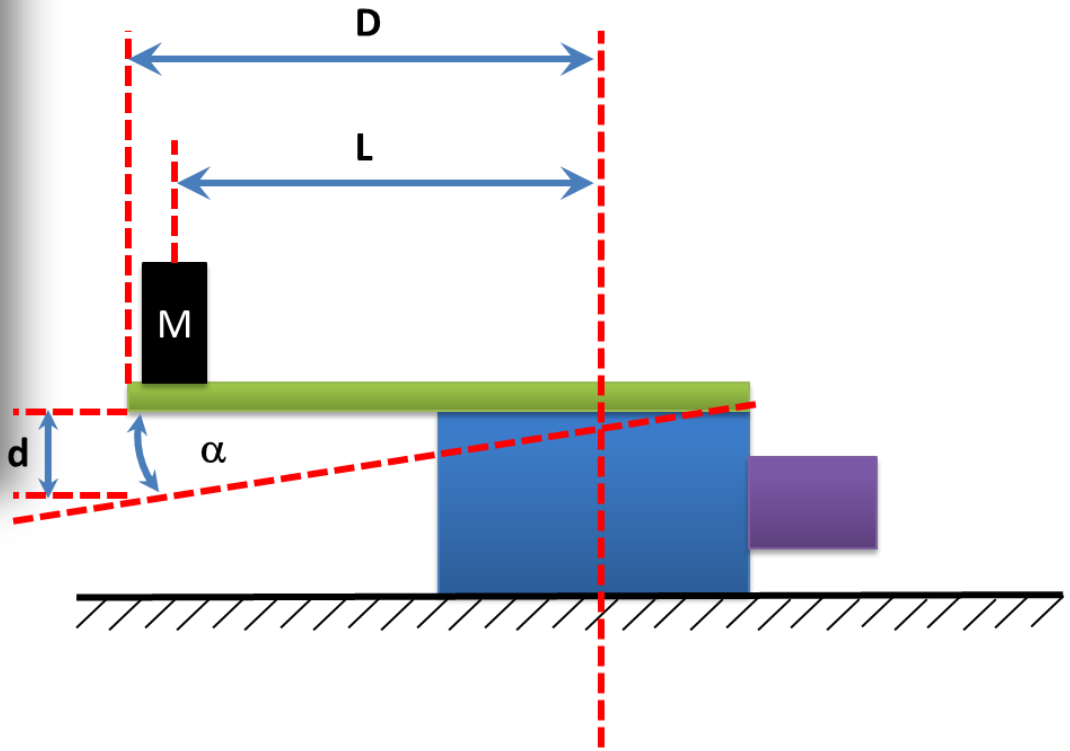
Case Study 2: Dynamic stiffness measurements



Case Study 2: Static stiffness measurement

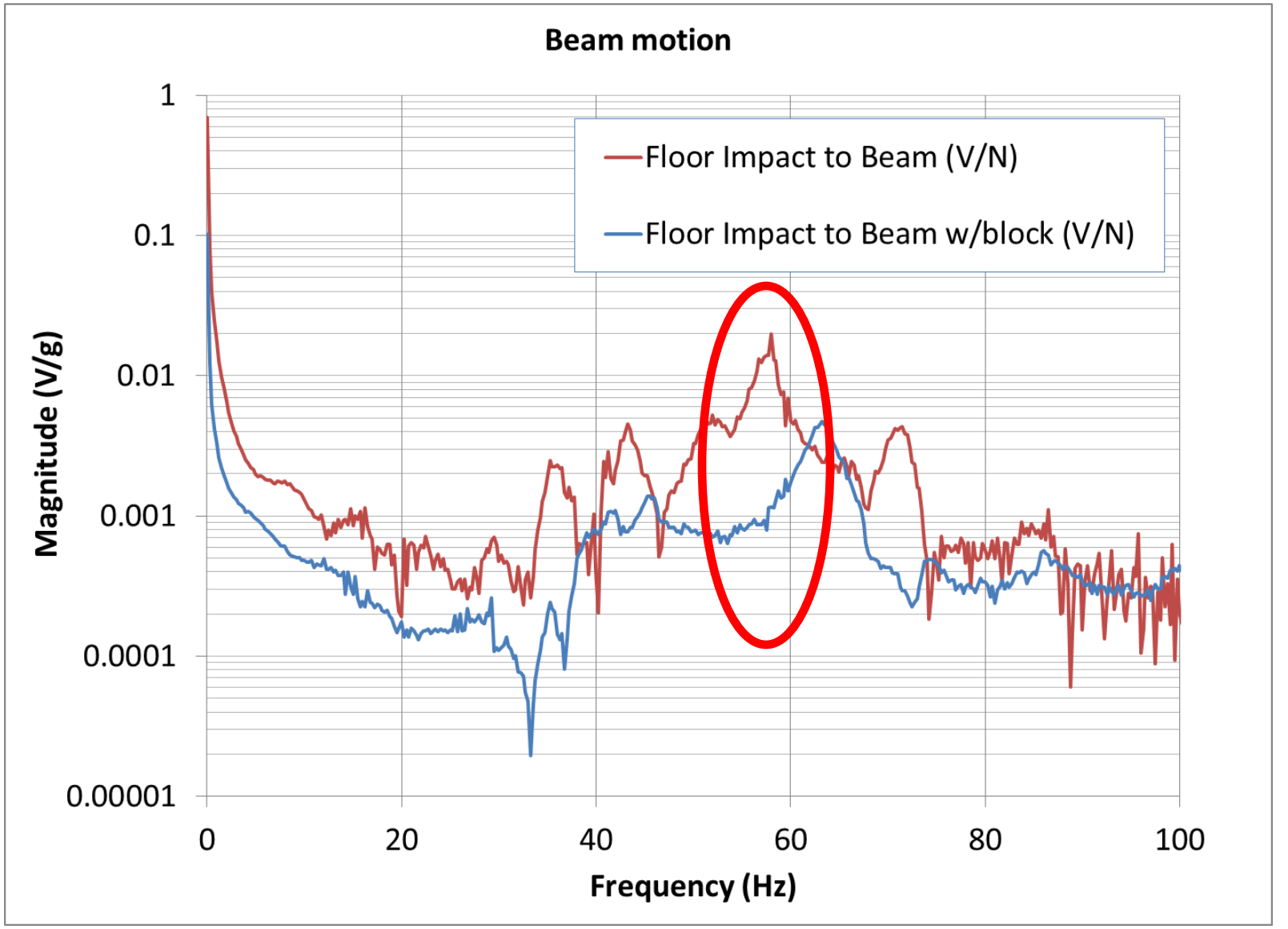


$$K_{XX} = T/\alpha$$



- Static stiffness measurement: ~37000 N*m/rad
- Dynamic stiffness measurement: ~18000 to 20000 N*m/rad
- This is *very* compliant as an APS-designed stage has stiffness of ~313000 N*m/rad

Case Study 2: Temporary mitigation



Current status

- A new vertical stage was specified and procured
  - Cross-roller bearing
  - Torsional stiffness of at least 325000 N*m/rad
- Four stages were ordered
- Custom item from vendor to fit existing volume and mounting holes
- Vendor was told we will check specification upon delivery
  - Stages as delivered do not meet specification
  - Conversation with vendor reveals different interpretation of cross-roller bearing guided stage

Conclusions

- Diagnosis
  - Check ambient environment
  - Measure beam motion with *sufficient bandwidth*
  - At some point, you need to open the tank
  - Modal analysis or impact measurements
  - Correlate beam motion and mechanical motions
- Good design practices
  - Reduce motion degrees of freedom
  - Select stiff bearings (both type and preload)
  - Use sufficient bearing separation
  - Hard points for cooling lines
  - Avoid cantilevered loads
  - Trust but verify if application is demanding

Cheers mates!

With my collaborators: Mark Erdmann, Alan Kastengren, and Barry Lai

Background

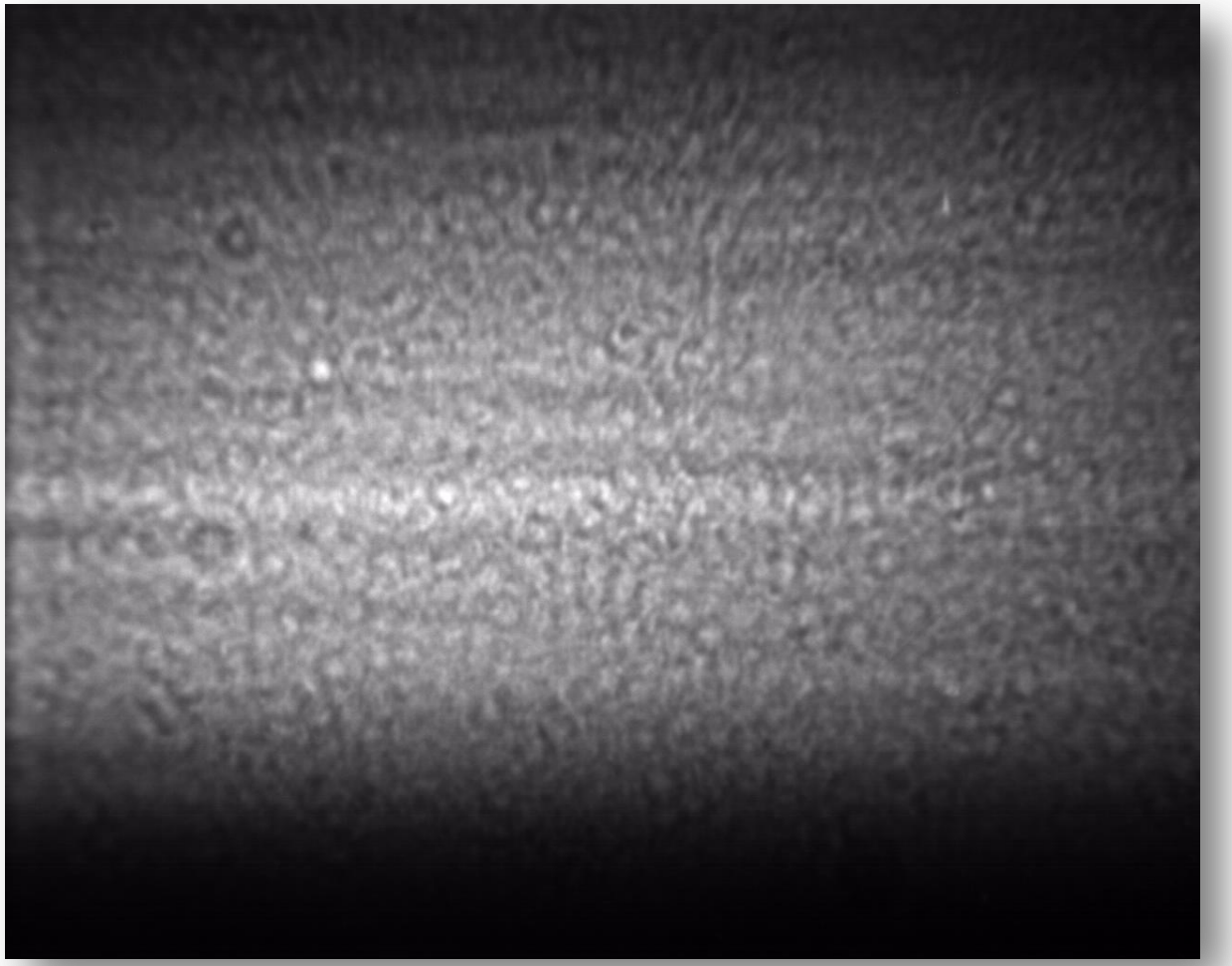
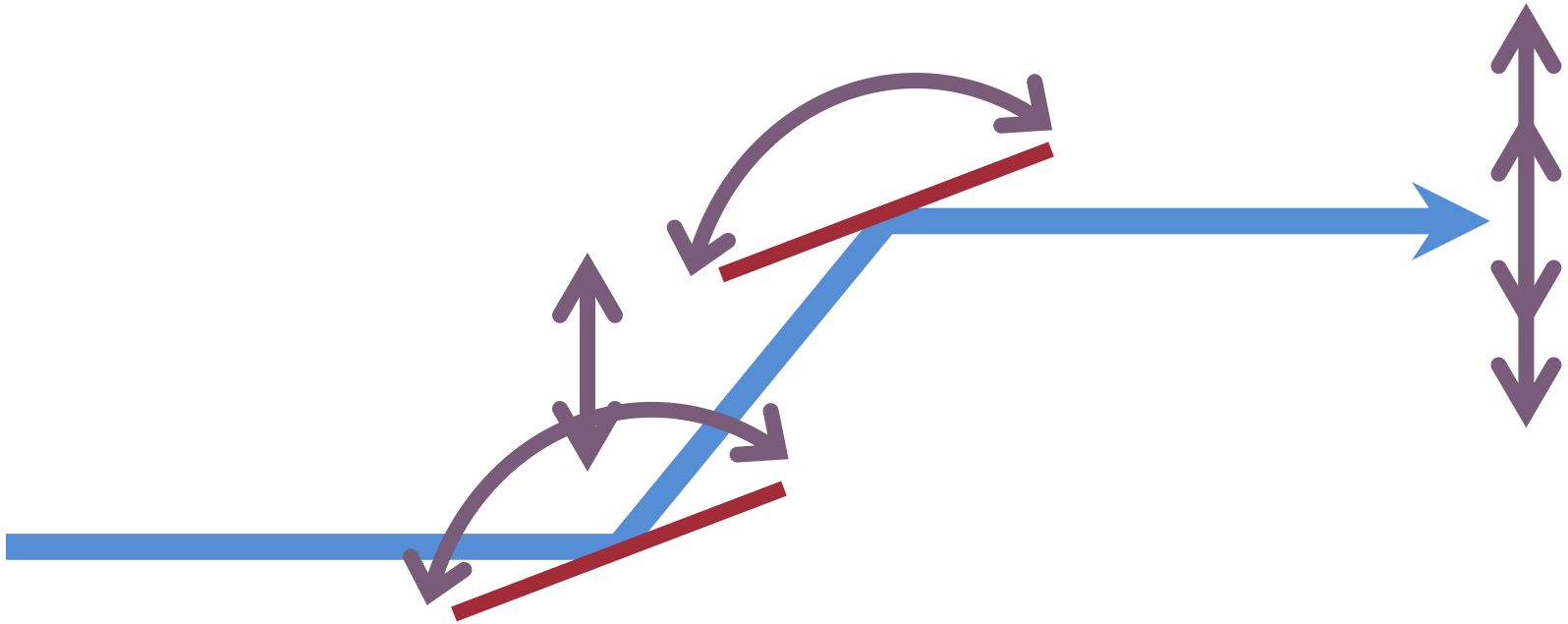


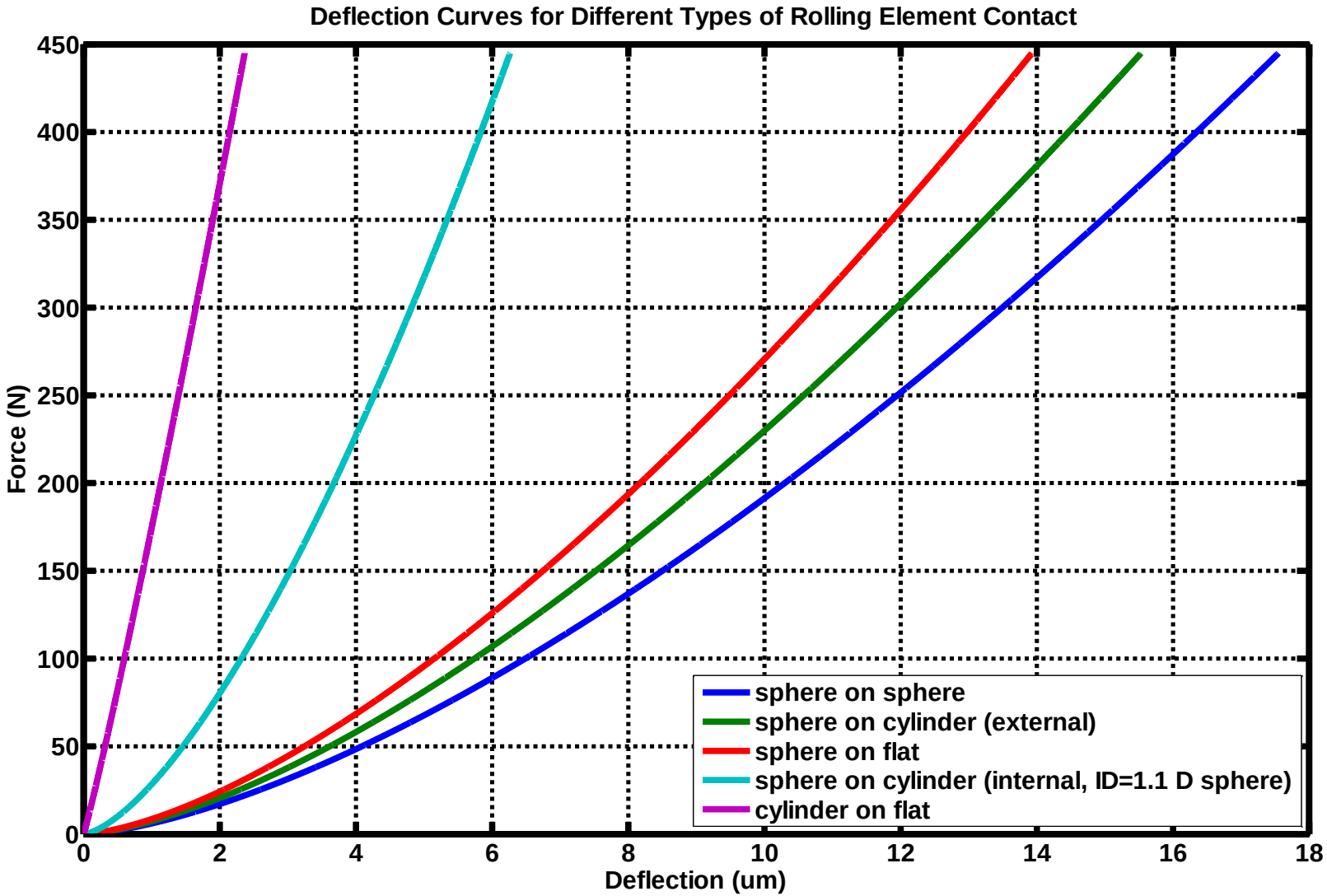
Image of beam from S02 ID Double Multilayer Monochromator

Background: Crystal perturbations and beam motion



Small translations and rotations at monochromator (a) lead to large beam motion at endstation

Background: Why might an instrument be susceptible?



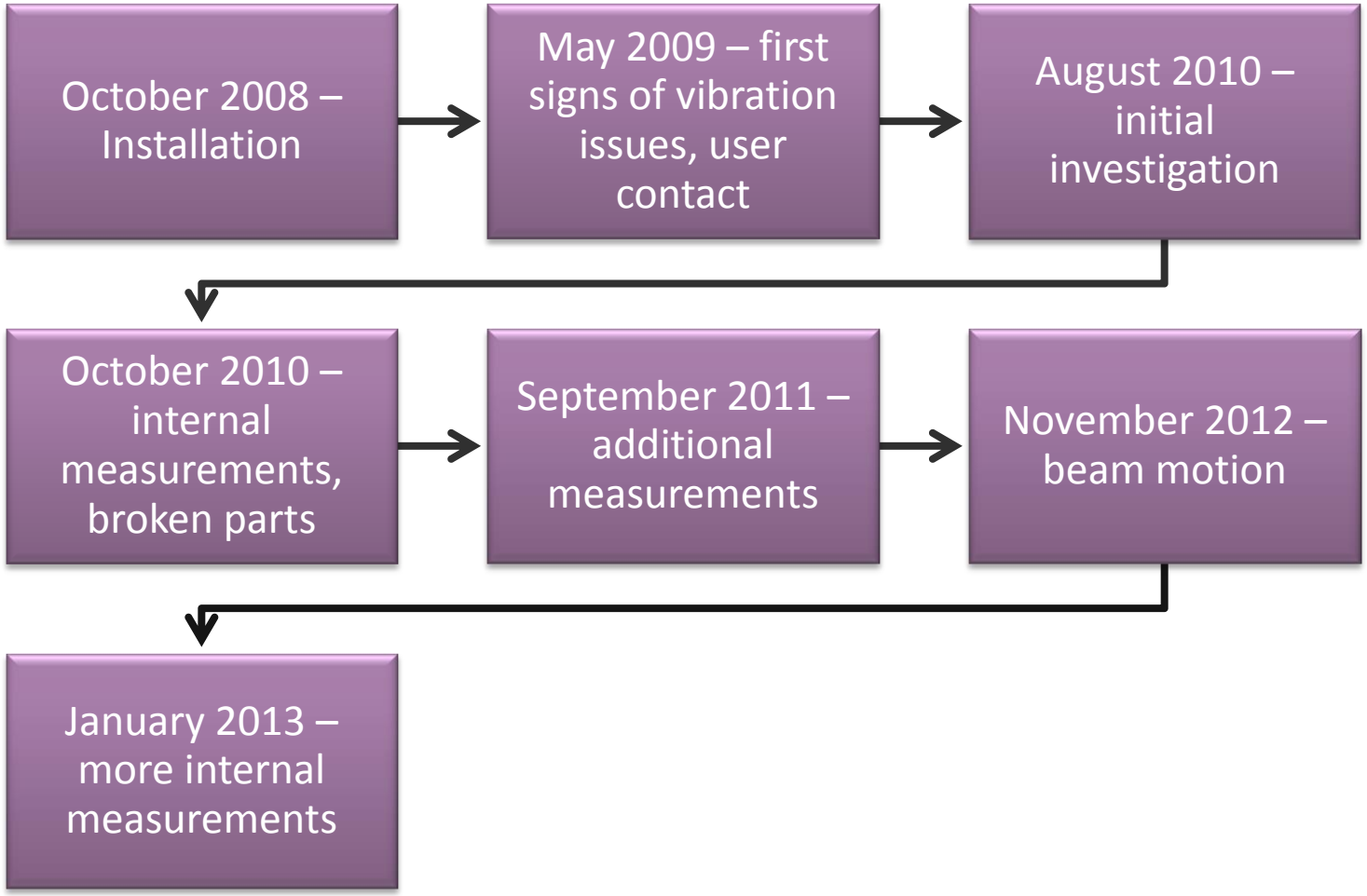
Background: Tools of the trade

- Data Acquisition – Data Physics Abacus
- Accelerometers
  - PCB 393B31, single axis, 635 grams, 1 nm/√Hz @ 7Hz
  - PCB 393B05, single axis, 50 grams, 10 nm/√Hz @ 7Hz
  - PCB 356B18, triaxial, 25 grams

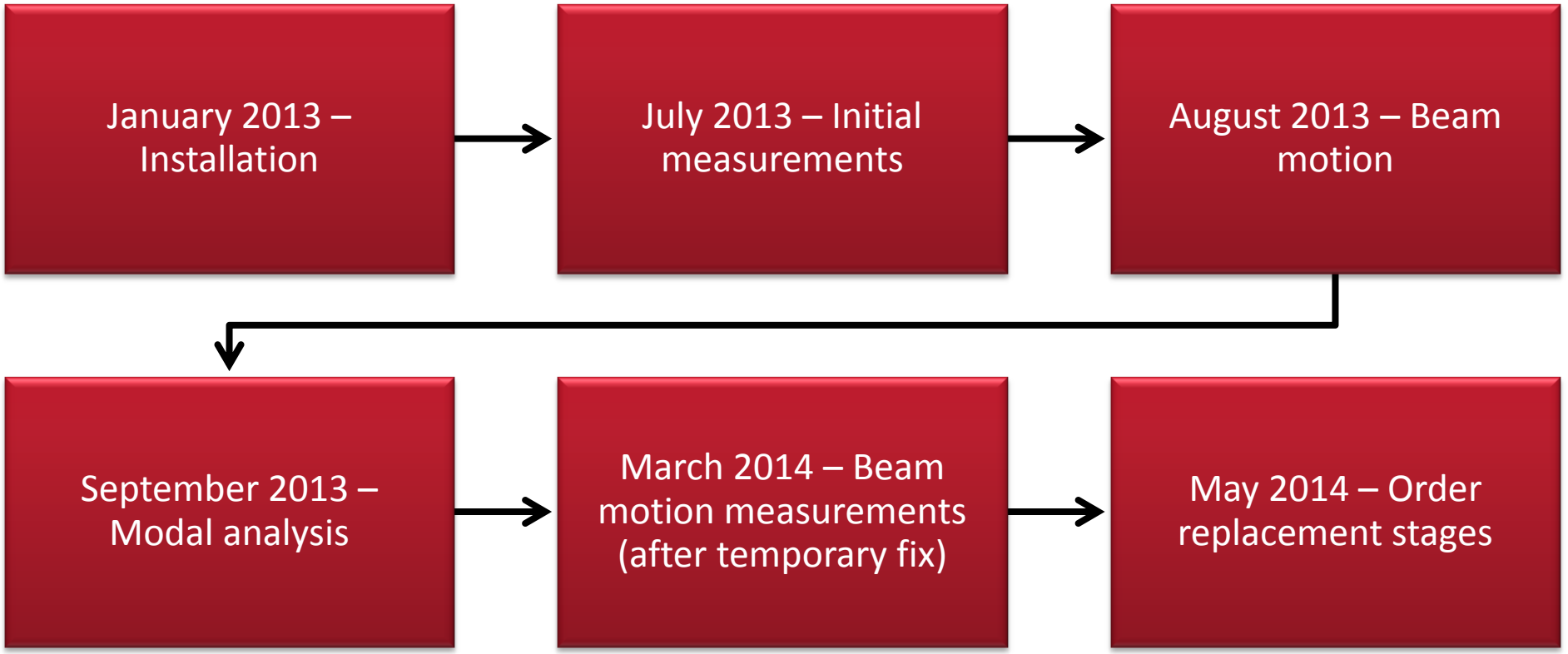
- Impact hammers
  - PCB 086E80, 4.8 grams
  - B&K 8202, 402 grams
  - PCB 086D50, 5.5 kilograms

- Polytec OFV-534 Laser Doppler Vibrometer
- Modal analysis can be used to estimate stiffness, and mode shapes (as opposed to operating shapes)

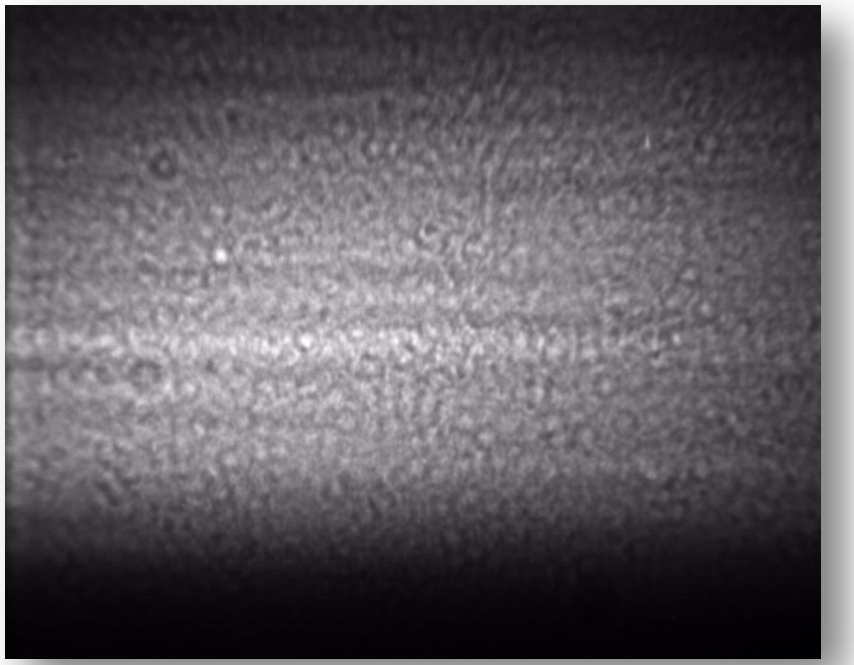
Case Study 1: Timeline



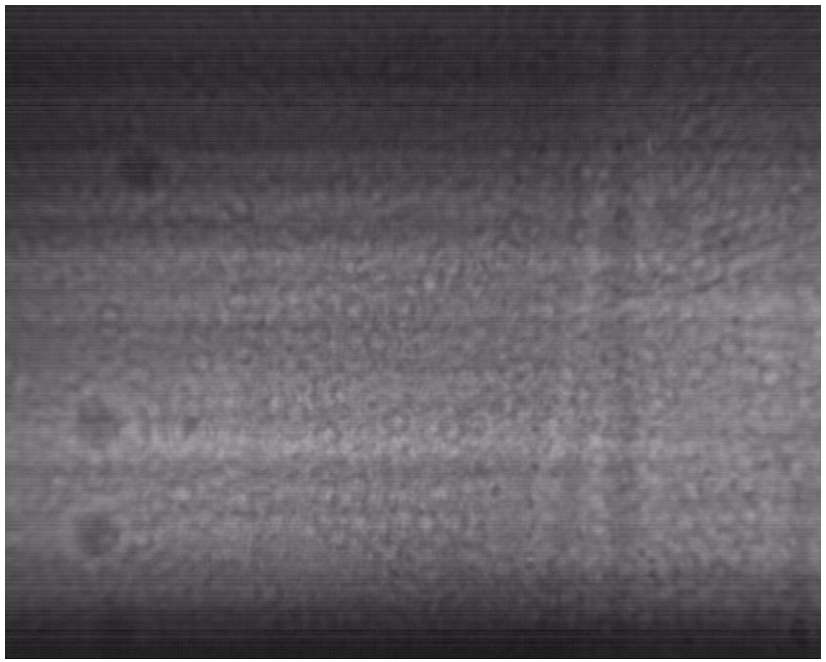
Case Study 2: Timeline



Temporary mitigation: Before and after

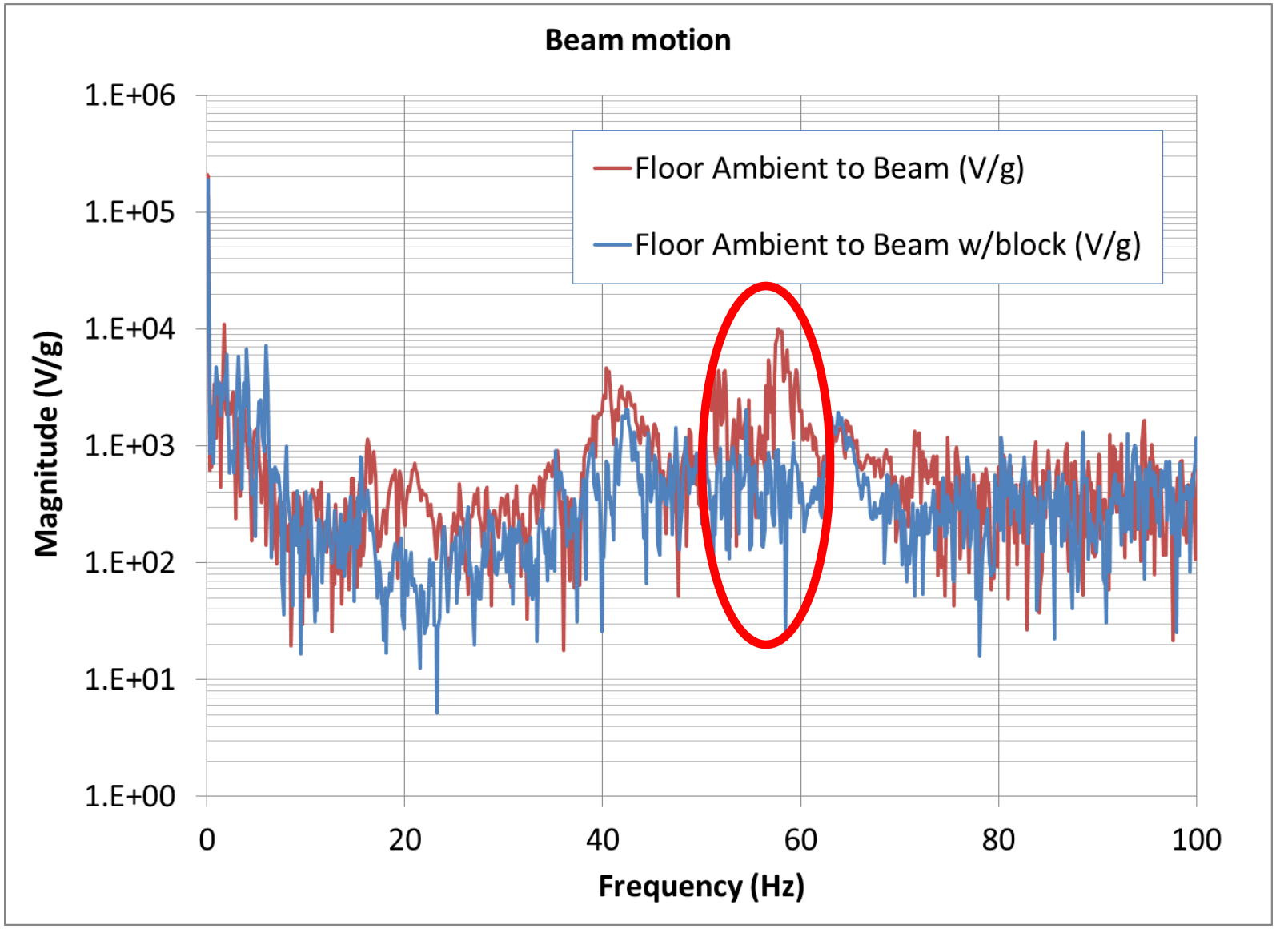


Before stage removal



With aluminum block

Temporary mitigation: Before and after



Summary of our method

1. Measure the ambient ground and beam motion
2. Try perturbing stages and measure beam motion
3. Measure beam motion Frequency Response Function (FRF)
4. Measure ambient motion of crystal holders
5. Measure impact-excited FRFs of crystal holders
6. Identify mode shapes and natural frequencies of crystal motion system
7. Correlate beam motion and crystal resonances
8. Correlate dynamic and static stiffness measurements
9. Remove, alter, or replace suspect components
10. Recheck beam motion